# NAVAL POSTGRADUATE SCHOOL
# Monterey, California

# THESIS

**HUMAN FACTORS ANALYSIS OF U.S. NAVY AFLOAT HAZARDOUS MATERIAL MISHAPS**

by

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June 2000

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Personnel aboard U.S. Naval vessels face risk of occupational injury and illness. A substantial part of that risk involves incidents, or cases of exposure to hazardous materials (HAZMAT). Due to the nature of this type of risk, there are many opportunities to improve safety and readiness and to reduce the number of workdays lost to injury. For the period from CY94 – CY98 there are 627 HAZMAT mishaps involving 820 personnel onboard U. S. Navy surface ships. HAZMAT root causal factors are identified through the evaluation of Special Case Mishap Reports maintained by the Naval Safety Center. 89% of these mishaps are attributable to human error. Failure to use personal protective equipment (30.0%) and failure to recognize a hazardous situation (24.6%) are the primary reasons given for the mishaps. Comparisons are made between HAZMAT, electrical shock and back injury mishaps. While minor differences exist between these types of mishaps, overall there are many commonalities that may be observed. Most are relatively minor as classified by severity, occur aboard Carriers, and involve personnel in the E-3 to E-5 rank range.


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**HUMAN FACTORS ANALYSIS OF U.S. NAVY AFLOAT HAZARDOUS MATERIAL MISHAPS**

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# ABSTRACT

Personnel aboard U.S. Naval vessels face risk of occupational injury and illness. A substantial part of that risk involves incidents, or cases of exposure to hazardous materials (HAZMAT). Due to the nature of this type of risk, there are many opportunities to improve safety and readiness and to reduce the number of workdays lost to injury. For the period from CY94 – CY98 there are 627 HAZMAT mishaps involving 820 personnel onboard U. S. Navy surface ships. HAZMAT root causal factors are identified through the evaluation of Special Case Mishap Reports maintained by the Naval Safety Center. 89% of these mishaps are attributable to human error. Failure to use personal protective equipment (30.0%) and failure to recognize a hazardous situation (24.6%) are the primary reasons given for the mishaps. Comparisons are made between HAZMAT, electrical shock and back injury mishaps. While minor differences exist between these types of mishaps, overall there are many commonalities that may be observed. Most are relatively minor as classified by severity, occur aboard Carriers, and involve personnel in the E-3 to E-5 rank range.

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## TABLE OF CONTENTS

I. INTRODUCTION ..... 1

A. BACKGROUND ..... 1
B. PURPOSE AND RATIONALE ..... 3
C. DEFINITIONS ..... 4
D. SCOPE ..... 4

II. LITERATURE REVIEW ..... 7

A. OVERVIEW ..... 7
B. ACCIDENTS AND HUMAN ERROR ..... 7
C. ACCIDENT PREVENTION ..... 8
D. ACCIDENT CAUSATION ..... 8
E. ACCIDENT INVESTIGATION ..... 14
F. ACCIDENT REPORTING ..... 15
G. ACCIDENT ANALYSIS ..... 18
H. HAZARDOUS MATERIALS ..... 19
I. SUMMARY ..... 25

III. METHODOLOGY ..... 27

A. RESEARCH APPROACH ..... 27
B. HAZARDOUS MATERIAL EXPOSURES ..... 27
C. PROCEDURE ..... 28
D. DATA ANALYSIS ..... 28

IV. RESULTS ..... 31

A. HAZARDOUS MATERIAL MISHAPS ..... 31
B. DATA EXPLORATION ..... 31
C. HUMAN FACTORS ANALYSIS ..... 38
D. POISSON MODEL OF MISHAPS ..... 41
E. MISHAP COMPARISONS ..... 43

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS ..... 49

A. SUMMARY ..... 49
B. CONCLUSIONS ..... 51
C. RECOMMENDATIONS ..... 52

APPENDIX A. SPECIAL CASE MISHAP REPORT EXAMPLE ..... 55

APPENDIX B. CY94 - CY98 STOCHASTIC MODELING OF HAZMAT MISHAPS ..... 59

LIST OF REFERENCES ..... 61

INITIAL DISTRIBUTION LIST ..... 65

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## LIST OF FIGURES

Figure 1. Histogram of HAZMAT Mishap Victims by Age .......... 34

Figure 2. Mishap Occurrences per Ship .......... 43

Figure 3. Mishap Occurrences per 1,000 Personnel .......... 44

Figure 4. Mishap Occurrences by Severity .......... 45

Figure 5. Mishap Occurrences by Ship Type .......... 45

Figure 6. Mishap Occurrences by Rank .......... 46

Figure 7. Mishap Occurrences by Gender .......... 46

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## LIST OF TABLES

Table 1. HAZMAT Mishap Occurrence Rates by Year ........ 31

Table 2. Mean Number of Personnel per HAZMAT Mishap by Year and Parent Command ........ 32

Table 3. Number of Single and Multiple HAZMAT Mishap Events by Year ........ 32

Table 4. Individual HAZMAT Mishap Severity by Year ........ 33

Table 5. HAZMAT Mishap Severity by Parent Command and Year ........ 33

Table 6. HAZMAT Mishaps by Gender and Year ........ 34

Table 7. HAZMAT Mishaps by Rank and Year ........ 34

Table 8. HAZMAT Mishaps by Body Part and Year ........ 35

Table 9. HAZMAT Mishaps by Vessel Type and Year ........ 36

Table 10. HAZMAT Mishap Rates for Carriers by Year ........ 36

Table 11. HAZMAT Mishaps by Evolution and Year ........ 36

Table 12. HAZMAT Mishaps by Ship Status and Year ........ 37

Table 13. HAZMAT Mishaps by Duty Station and Year ........ 37

Table 14. HAZMAT Mishaps by Parent Command and Year ........ 38

Table 15. Normalized HAZMAT Mishap Data by Surface and Air Groups by Year ... 38

Table 16. HAZMAT Mishap Activities by Year ........ 39

Table 17. HAZMAT Mishap Causes ........ 40

Table 18. HAZMAT Mishaps - Why ........ 41

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## LIST OF ACRONYMS

| | |
|---|---|
| CNO | Chief of Naval Operations |
| CYxx | Calendar Year xx |
| DOD | Department of Defense |
| DON | Department of the Navy |
| FIFRA | Fungicide and Rodenticide Act |
| HAZMAT | Hazardous Material |
| NAVOSH | Navy Occupational Safety and Health |
| NAVSAFECEN | Naval Safety Center |
| NSC | National Safety Council |
| NCIS | National Council of Industrial Safety |
| OSHA | Occupational Safety and Health Administration |
| PPE | Personal Protective Equipment |
| SECNAV | Secretary of the Navy |
| SCM | Special Case Mishap |

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# EXECUTIVE SUMMARY

Chemicals and other hazardous materials (HAZMAT) are unavoidable aboard U.S. Navy vessels. Interaction with these materials requires personnel to adhere to established safety measures to avoid injury. For the period from January 1, 1994 through December 31, 1998, there are 627 HAZMAT mishaps involving 820 personnel onboard U. S. Navy surface ships. Reactions to toxic materials may vary greatly depending on whether the material is explosive or flammable, a cryogen, toxic, or radioactive. There are three ways that chemical agents can harm an individual. The first is by contact with or absorption through the respiratory tract. The second is by contact with or absorption through the skin. The third is by contact with or absorption through the digestive tract. This would involve consumption of the material in question. To reduce the number of HAZMAT injuries, a clear understanding of causal factors is needed. It is also important to know how these mishaps compare to similar occupational mishaps. Thus, in this thesis, we conduct a human factors analysis of HAZMAT mishaps and compare them to back injury and electrical shock mishaps.

For the time frame from CY94 – CY98 the number of HAZMAT mishaps per surface ship ranges from .39 to .58 and the same number of mishaps per thousand personnel ranges from .95 to 1.26. Of the 627 mishaps for this time frame a vast majority involve a single individual (90.3%), are of Class "C" or less in severity (98.3%), and involve males (89.9%). The reported median age for an individual involved in a HAZMAT mishap is 23.6 years of age and the most common rank is E-3 (30.7%). Most injuries incurred by individuals are either to their eyes (54.9%) or to their lungs (19.1%). Almost half (48.9%) of personnel involved in HAZMAT mishaps are attached to Carriers

and 42.3% are injured while the ship's evolution is classified as independent steaming. SURFPAC and SURFLANT report similar levels of mishaps while AIRLANT reports a much greater level of mishaps than SURFLANT. This may be indicative of varying training, reporting techniques, or mission requirements.

A human factors analysis of the data reveals that over 89% of the mishaps in this study are attributable to human error. Another 6.6% are attributable to the environment. Individuals involved in either maintenance (27.7%) or housekeeping (18.9%) actions account for a majority of the mishaps. Among the reasons given for HAZMAT mishaps are failure to use personal protective equipment (PPE) at 30.0%, failure to recognize a hazardous situation (24.6%), and failure to use proper caution for a known risk (10.8%). The primary reason given is individual inattentiveness (29.0%) followed by insufficient experience, skill, or training (11.2%) and haste (9.0%).

In comparing HAZMAT mishaps with the other two most frequently reported types of mishaps, electrical shock and back injuries, electrical shock mishaps occur with the greatest frequency, but with less severity. Of electrical shock mishaps, 93.0% are Class "D" compared with 54.6% for back injuries and 81.2% for HAZMAT. HAZMAT mishaps are more frequent among personnel of E-3 rank while back injury and electrical shock mishaps occur more frequently among the E-4s. As a percentage of all individuals involved in mishaps, more males are injured in electrical shock mishaps (94.3%) as compared to HAZMAT (89.9%) or back injury (87.2%).

From these findings, we conclude that a concerted effort focusing future intervention strategies at Aircraft Carriers is imperative. Specifically, attention to causal factors including improper use of PPE, inattentiveness, and haste should be included.

Procedures, particularly those that involve the proper use and purpose of PPE, should be reviewed and more strictly enforced. Training which emphasizes increased communication and application of proper procedures will not only reduce further mishaps, but also foster a culture of safety adherence.

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## DEDICATION

This thesis is dedicated to my loving wife, Jennifer, and to Chad, Connor, Chase, and Maren, our four beautiful children. Their love and patience during these past two years has been an inspiration.

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# I. INTRODUCTION

## A. BACKGROUND

Though the passage of the Occupational Safety and Health Act in 1970 is primarily targeted at the civilian sector, it and subsequent legislation serve to formalize the military's occupational safety and health programs. Today's Navy is primarily guided in these areas by four publications; 1) SECNAV Instruction 5100.10G, "Department of the Navy Policy for Safety, Mishap Prevention, and Occupational Health Programs", 2) OPNAVINST 5100.8G, "Navy Safety and Occupational Safety and Health Program", 3) OPNAVINST 5100.23C, "Navy Occupational Safety and Health (NAVOSH) Program Manual", and 4) OPNAVINST 5100.21B, "Afloat Mishap Investigation and Reporting". In accordance with these guidelines, a Special Case Mishap (SCM) of any severity occurring on board ship or to the ship's on-duty personnel ashore must be reported. Through the evaluation of SCMs, this study attempts to identify patterns or root causes of SCM injury types in order to suggest prevention strategies to reduce or at least avoid such incidents.

SCMs include electric shocks, hazardous material, chemical, or toxic exposures requiring medical attention, back injuries requiring medical attention, and incidents involving explosives, oxidizers, incendiaries, explosive systems, or chemical warfare agents (DON, 1997a). SCMs are related to personnel injuries of active duty members aboard afloat combatants and may be classified as Class A, B, or C depending on the level of loss of life and/or cost of the incident; however most do not achieve the thresholds necessary for such a classification. Once a SCM is reported, the Naval Safety Center (NSC) enters the data from the report into their Safety Information Management

System (SIMS). Through the collection and recording of this data, the NSC is able to evaluate and distribute information related to mishaps in the hope of raising awareness of these incidents.

There are two recent human factors studies of SCM reports, Sciretta (1999) and Lindly (1999). Sciretta (1999) examines Electrical Shock SCMs. His analysis consists of classifying Electrical Shock SCMs using scenario analysis and identifying salient human factors patterns through data tabulation. Potential intervention strategies are then developed and evaluated for effectiveness using stochastic modeling. Lindly (1999), in an effort to examine back injuries, also uses human factors analysis and probabilistic modeling to predict outcomes of intervention strategies. Lindly develops an instrument to provide decision-makers with a tool to identify potentially effective intervention. Both studies explore human factors as an integral part of SCMs and attempt to suggest intervention strategies to reduce them.

Personnel aboard U.S. Naval vessels face inherent risk of occupational injury and illness by virtue of their job and work environment. A substantial part of that risk involves incidents, or cases of exposure to hazardous materials. Sacarello (1993) defines hazardous materials as "a broad term encompassing any material, including substances and wastes, that may pose an unreasonable risk to health, safety, property, or the environment, when they exist in specific quantities and forms" (Introduction). Due to the nature of this type of risk, there are many opportunities to improve safety and readiness while reducing the number of workdays lost to injury.

The first step toward suggesting preventive strategies must be to understand the hazardous exposure incidents themselves and to identify and pinpoint the main causes.

Only then can limited resources, such as training, be allocated to diminish potential hazards. By analyzing the SCM reports collected and maintained by the NSC, these characteristics can be identified. SCM reports contain information such as date, time, location, personal and property cost, fatality/injuries summary, and a variety of information about the individual and ship involved. Through exhaustive analysis, this thesis evaluates the possible impact of specific intervention targeted at identifiable groups of individuals at risk and or tasks that put them at risk in order to reduce costs in dollars and lost workdays.

## B. PURPOSE AND RATIONALE

The purpose of this study is to analyze and evaluate data from hazardous material, chemical, or toxic exposure SCMs, in order to identify significant trends or patterns. This information is in turn used to allocate scarce resources through the identification of potential intervention strategies to help eliminate, reduce, or attenuate such occurrences. This study investigates the following questions:

1. Can patterns and common features of hazardous material mishaps be identified?
2. Can human factors be identified as common causes in hazardous material mishaps?
3. Can potential intervention strategies be identified to alleviate possible future mishaps?

## C. DEFINITIONS

Mishaps are defined as follows (DON, 1997a):

1. Class "A" Mishap. A mishap involving one or more of the following: (1) property damage greater than or equal to $1,000,000; (2) loss of life; or (3) permanent disability.

2. Class "B" Mishap. A mishap involving one or more of the following: (1) property damage between $200,000 and $1,000,000; (2) permanent partial disability; or (3) hospitalization of five or more people.

3. Class "C" Mishap. A mishap involving one or more of the following: (1) property damage between $10,000 and $200,000; (2) an injury preventing an individual from performing regularly scheduled duty or work beyond the day or shift on which it occurred; or (3) nonfatal illness or disability causing loss of time from work or disability at any time.

4. Class "D" Mishap. Special Case Mishaps (SCM) not meeting the reporting criteria of Class A, B, or C.

## D. SCOPE

SCM data, as it relates to cases of hazardous material, chemical, or toxic exposure requiring medical attention for military personnel assigned to afloat units, will be examined and modeled for the time period between 1 January 1994 and 31 December 1998. The focus of this study is a statistical analysis and study of human causal factors of hazardous material incidents. Chapter II provides a basis for understanding human error and accident prevention, causation, investigation, reporting, analysis, and hazardous materials. Chapter III presents a discussion of the methodology used in this study. Results

of data analysis, human factors analysis, stochastic modeling and comparisons to electrical shock and back injury mishaps are presented in Chapter IV. Chapter V summarizes previous chapters and provides conclusions and recommendations as they relate to the material.

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# II. LITERATURE REVIEW

## A. OVERVIEW

The intent of this review is to provide a broad understanding of accidents and how human factors play a significant role in their occurrence. It focuses on accident causation, investigation, reporting, prevention, analysis and more specifically, hazardous material mishaps. The literature consulted for this research includes published textbooks and articles covering the subjects of human factors, safety, accident prevention, and hazardous materials.

## B. ACCIDENTS AND HUMAN ERROR

In the field of accident prevention, key terms are either not defined or defined in such a variety of ways that no practical standard exists. Two major features of most literature definitions and references related to accidents are the concepts of accidents that are unplanned and undesirable (e.g. Arbous & Kerrich, 1953; Heinrich, 1959; Suchman, 1964). This can also be seen in Stramler's (1993) definition of human error as "An inappropriate response by a system, whether of commission, omission, inadequacy or timing; any discrepancy between an observed or calculated value, and the expected value, or a value known to be correct" (p. 104).

While the inclusion of an injury in any given accident is not mandatory by most definitions, it surely increases the likelihood that the event in question will be identified as 'an accident' (Suchman, 1964). Other issues which have contributed to vagueness surrounding the understanding and study of accidents is the interchangeable use of the terms 'accident' and 'injury'. In most cases, this usage has resulted from workplace studies where accidents are defined as the occurrence of some type of minimal injury

(Powell, 1971). Thus, accident and injury become one and the same. Other authors, Lagerlof (1975), Kieback (1988), and Saari (1982) suggest that the definition of 'accident' depend on the legal framework of the situation.

For the purposes of this research, the definition of 'accident' taken from Heinrich, Peterson, and Roos (1980) is "An unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof" (p. 23). As previously pointed out, this definition also contains the features of being unplanned and undesirable ("results in personal injury").

## C. ACCIDENT PREVENTION

McElroy (1974, p.151) states that a successful accident prevention program involves at least four fundamental activities;

1. A study of all working areas to detect and eliminate or control physical or environmental hazards which contribute to accidents;
2. A study of all operating methods and practices;
3. Education, instruction, training and discipline to minimize human factors which contribute to accidents;
4. For cause analysis, a thorough investigation of at least every accident which results in a disabling injury or lost workdays to determine contributing circumstances.

This outlook stresses the desire to investigate and determine causation before accidents occur. All too often, a human factors investigation is not conducted till after an accident has occurred. This is not a fundamentally sound or responsible way to conduct business.

## D. ACCIDENT CAUSATION

The concept of causation is considered extremely important in that the identification of factors that suggest prevention strategies. Unfortunately, in most cases a predominant root cause, which may contribute to a higher-than-chance probability, will

be identified while several other causes may go unobserved. Furthermore, a root cause such as operator stress may not necessarily be sufficient to cause the accident each time it is present. A different investigator may uncover other causes, such as poor design, or even concentrate on factors that contributed to the stress that resulted in an accident.

Goetsch (1996) identifies the most prevalent theories of accident causation. These theories are the: (1) Domino Theory; (2) Human Factors Theory, (3) Accident/Incident Theory; (4) Epidemiological Theory; and (5) Systems Theory. In order to explain why accidents happen most models employ one of these theories to predict and prevent accidents. The following sections review each theory and provide an example to demonstrate the fundamental basis of each theory.

**1. Domino Theory**

Heinrich (1936) is the first to suggest the "domino" theory of accidents. His idea is that accidents are a sequence of events that occur in a predetermined relationship with one event proceeding and following another, just like dominos. The five main factors of his theory are: (1) ancestry and social environment; (2) fault of person; (3) unsafe act and/or mechanical or physical hazard; (4) accident; and (5) injury. The most fundamental points of this theory are that injuries are caused by the action of preceding factors and that the removal of the central factor, the unsafe act or hazardous condition, negates the action of the preceding factors and thereby prevents the accident. This view changes the focus of investigations to the events involved, rather than the existing conditions. An example demonstrating the domino theory would be an instance where summer heat causes workers to discard personal protective equipment thereby exposing them to hazardous materials.

Researchers such as Bird and O'Shell (1973) feel that Heinrich's theory attributes too much cause to factors internal to workers and neglects the importance of external factors. Their model introduces the thought of managerial error into the accident causation sequence. The revised domino theory is: (1) Injuries are caused by accidents; (2) For every accident there are immediate causes that are related to operational errors; (3) Operational errors are only symptoms of deeper underlying or basic causes related to management errors; (4) The absence of a system of effective control permits the existence of the factors referred to as basic causes. Bird asserts that by eliminating one or more of the factors causing the accident would prevent the accident from occurring.

### 2. Human Factors Theory

The human factors theory is similar to the domino theory in that it focuses on a chain of events leading to an accident, but with the root cause being attributable to some form of human error. Heinrich, Peterson & Roos first described this theory, in 1980. They identify the factors that lead to the human error as overload, inappropriate activities, and inappropriate responses. Overload is the discrepancy between a given individuals capacity and the load that person is carrying in a given state. Factors, which can affect a person's capacity, include their natural ability, training, fatigue, stress, and physical condition. Inappropriate activities consist of performing tasks improperly either because the individual does not know any better or because he misjudges the degree of risk involved with the task. Inappropriate responses exist in situations where an individual is exposed to a basic incongruity such as detecting but not correcting a hazard, removing safeguards from machines and equipment, or ignoring safety. There are many cases aboard ships that demonstrate the human factors theory as it relates to hazardous material.

Perhaps an individual is using jet fuel to clean a piece of equipment when the spray is blown into their face. Human factors which contribute to this mishap are selection of an improper cleaning solution, misjudging the risk involved, and ignoring safety by not using the proper personal protective equipment.

Reason (1990) defines human error as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency". He further classifies human error in one of three ways. The first type of classification is mistakes. A mistake is a planning error where actions go as planned but the plan is not good enough. Mistakes can either be considered as a failure of expertise or as a lack of expertise. The second classification is a lapse. A lapse is a memory failure that does not manifest itself in actual behavior and may only be apparent to the person who experiences it. The third type of classification is a slip. This is a failure that is the result of poor execution of a good plan.

### 3. Accident/Incident Theory

Peterson (1975) and Heinrich, Peterson & Roos (1980) present the accident/incident theory. It states that the cause of accidents can be traced back to human error, or systems failure, or both. It also adds new elements to the human factors theory such as decision to err and systems failure. Decision to err is a form of human error, which may be unconscious or conscious and based on some type of logic. Systems failure involves the potential for a causal relationship between an organizations managerial contribution to safety practices and corrective measures. An example of the accident/incident theory is where individuals aboard a ship that has proper safety controls

and procedures in place still perform unsafe acts. The controls and procedures are adequate, but not adhered to and the worker circumvents them in order to complete the task as soon as possible.

Fault tree analysis shows the logical relationship of the factors increasing liability and the various error probabilities. One such method that provides structure and a broad, detailed checklist for such accident investigations is Johnson's (1975) Management Oversight and Risk Tree (MORT). This is an adaptation of the systems safety logic tree method and facilitates the search for safety problems on the checklist. While it has several drawbacks such as assuming a thorough knowledge of the accident situation and is limited to items actually on the list it is a valuable way to chart many aspects of the accident.

**4. Epidemiological Theory**

Epidemiology theory states that models used for studying and determining the causal relationships between environmental factors and disease can also be used to study the same relationships between environmental factors and accidents (Goetsch, 1996). The crucial components of this theory are predisposition characteristics and situational characteristics. Predispositional characteristics are composed of susceptibility of people, awareness, and environmental factors. Situational characteristics include risk assessment by individuals, peer pressure, priorities of the supervisor, and attitude. For example, a worker is given a broom and a hose and assigned to clean a large tub that has previously been used to hold toxic materials. The worker is then permanently disabled. The predispositional characteristic is the workers desire to make his boss happy and the situational factor is the boss' long record of ignoring environmental concerns.

Andersson and Lagerlof (1983) use these methods to study occupational injuries in Sweden that resulted in the implementation of a new injury notification form. This form provided a more reliable basis for accident prevention measures. The Swedish Occupational Injury Information System (ISA) contains all occupational accidents and diseases in Sweden reported by employers. Information is recorded as free-text to preserve detail and is also coded to provide faster access for statistical analysis. This system provides a basis of information that is necessary for prevention.

**5. Systems Theory**

System theory involves looking at several different aspects and how they interrelate and interact to cause an accident (Goetsch, 1996). Many variations of this theory exist. Simple models partition the components into people, machinery, or environment. Other models may also use environment and personal or people, but may include task, management, and material as possible categories. Regardless of the classification, it is important that possible causes in each category be investigated. In this way, all possible causes are more likely to be uncovered and the likelihood of looking at facts in isolation is reduced. An example of the systems theory would be when an inexperienced, untrained individual is asked to work on an older, less reliable piece of equipment while experiencing a high degree of stress and fatigue.

The most widely used systems theory of causation model is developed by Firenzie (1978). The components of this model not only included the aspects of person, machine, and environment, but also information, decisions, risks, and the task to be performed. Each of these aspects plays a part in the risk involved and probability that an accident will occur.

Many other theories of accident causation exist. The five forms discussed serve to reflect the many possible combinations and types of factors that can lead to the occurrence of an accident. While no one theory will help determine every incident of accident causation, it may be necessary to combine aspects of several theories depending on the situation (Goetsch, 1996). Also, one must be careful not to confuse cause with blame or fault. By its very nature, cause identification is equated with the identification of breakdowns of procedures and systems within the responsibility of defined parties. This may lead to counterproductive causal identification if the parties involved feel threatened or at risk.

## E. ACCIDENT INVESTIGATION

The idea that human factors plays a part in accident causation dates back to Newbold (1926) who writes "The cause of an accident is hardly ever simple: it may be mechanical, physical, physiological, psychological, or more probably a combination of some or all of these." It is not until the early seventies though, that authors start to discuss the context of accidents in human factors terms (e.g. Hale & Hale, 1970; Powell, P., Hale, M., Martin, J. & Simon, M., 1971). Some of the methodologies developed or modified include task analysis and the use of checklists. Uses of these human factors methodologies, it is argued, are better able to identify a wider spectrum of causes than earlier models (Edwards, 1981; Drury & Brill, 1983).

Some of the reasons for investigating accidents are to fulfill a legal requirement, determine the cost of an accident, determine compliance with applicable safety regulations, and to process workers' compensation claims (Blumenthal, 1970). The most important reason though, should be to find out the root causes of the accident and to

prevent similar accidents in the future. Regrettably, most investigations are not pursued to that point. They stop when they find what they consider to be a most important cause. This undermines the quality of the investigation and directly affects the success of the resulting corrective measures to prevent such accidents in the future (Hill, Byers, Rothblum, & Booth, 1994).

Another hindrance in the process of implementing the necessary corrective measures is the fact that those conducting the investigations are usually untrained with limited capabilities and funding to perform such investigations (Ferry, 1985). This is true especially of accidents involving U. S. Naval personnel. In most cases, an officer is chosen arbitrarily and assigned to investigate the accident with nothing but a deadline for reporting back. To take it one step further, Buck (1987) argues that waiting for an accident is an expensive way of conducting human factors studies. The point he is trying to make is that in many cases, accidents can be avoided altogether if human factors are integrated into designs and equipment from the very start. It is all too often the case that a simple design or procedural change could have prevented an accident.

## F. ACCIDENT REPORTING

Ideally, the collection of data related to accidents should be comprehensive, unbiased, and factual (Adams, 1974). This data can serve as an extremely important source of information and does not directly provide guidance about how injuries are to be prevented. Drury & Brill (1983) states, "Even if the epidemiological approach identifies something, it still remains to devise solutions." Too many times, individuals rely heavily on accident statistics alone to try and solve their problem. Before they go to the data they

should have specific questions in mind, and should draw from the relevant data that information which will help them.

Two types of records are normally found in databases, incidence and descriptive information (Greenberg, 1970). Incidence data pertains to such things as counts of events, cost, or severity of outcome. Descriptive information usually provides some type of narrative record of the incident.

Some of the more common types of incidence data include raw counts, frequency rates, severity rates, average days per lost-time case, and costs of benefits paid (Greenberg, 1970). Several of these rates require that they be normalized and most are disputed as not being adequate or meaningful indicators. Other approaches have tried to overcome these obstacles through the development of ratios and comparisons. One such approach involves computing the ratio of the rate, either frequency or severity, for one area and comparing it to the whole. An excess count method uses the number of accidents or lost days in excess of the expected number times the exposed workforce where the expected number is calculated from a standard rate. Further measures attempt to utilize lost time as an indicator or some type of cost such as medical or insured expenses.

Even these approaches are inherently flawed. As for lost days, studies have shown that patients receiving some form of compensation recover more slowly (Derebery & Tullis, 1983). In regards to medical or insured costs, the complexity of insurance policies, personal policies, and combination of these schemes confounds any method of computation (Laufer, 1987). Even if these flaws could be taken into account, there is still the problem of accounting for personal and socioeconomic factors. An individual's sex,

age, and experience can greatly influence the extent that the person is affected. One type of injury may be inconsequential for one person, but fully disabling for another.

Descriptive data also has several inherent flaws (Adams, 1981). In some cases, the narrative is translated into code for numerical analysis. This coding leaves the system open to interpretation and translation by the person doing the coding. This can cause great discrepancies based on how the individual codes the narrative and the categories available for coding. Taxonomies can be reliable, but they need to be consistent and exhaustive (Edwards, 1981). If not, the outcome may be unintentionally incorrect. Also, if the information is gathered in checklist form, there is no room for additional information. This may preclude the study from reaching the proper conclusion.

Another major concern and problem in accident reporting is the dilemma of underreporting. Various studies have been done on this topic (NBOSH, 1987; Kjellen & Larson, 1981). In one comparison of reports with observation of work and accidents, the amount of underreporting ranged from 30 percent to 95 percent (Powell et al, 1971). A prime factor in the large disparity of this range is due to the existence, perceived effectiveness, and approachability of a first aid or medical service. Other factors which may preclude the total reporting of accidents are attributed the individuals supervisor, medical staff, and safety officer. Once again, reporting may be compromised by the individual's adherence to regulations and policies, their interpretation of those regulations and definitions and pressures on individuals to reduce the number of accidents.

The percentage of unreported accidents is often taken to be 50 percent. But in any given situation, the actual number will depend on what the individual decides to report and on the definitions for various aspects of the accident. Interpretations of 'accident',

'injury', etc. by the individual involved in the accident as well as by those reporting and investigating it play a large part in the outcome of the data.

## G. ACCIDENT ANALYSIS

The root of proper accident analysis is sufficient and statistically accurate data (Drury & Brill, 1983). As previously discussed though, this is not usually the case. No amount of modern, high-powered computer or human analysis can detect patterns or trends for factors that are not found in the database. Inaccurate or incomplete databases usurp the goal of accident analysis, which is to identify specific casual factors of the mishap so that preventive measures can be developed to prevent future incidents. Therefore, no reliable study may be conducted based on databases alone. Further, investigation or task analysis is almost certainly required. Anderson (1983), in studying accidents on-board ships, discovers that relative reporting rates are not indicative of the relative risk of specific ships, nor is the needed diagnostic information captured by the reporting practices.

To create a data gathering system for consumer product accidents, Drury & Brill (1983) interview injured people, and develop product-specific frameworks to obtain information about task behaviors. They observe that each job activity is composed of a sequence of tasks and that accidents are the interaction between the task, the individual, the equipment, and the environment. These tasks, given certain limitations, may be considered useful when grouped into hazard patterns. No more than six scenarios should account for at least 90 percent of the investigations. Each scenario should suggest at least one feasible and effective intervention strategy, unique to that scenario. The scenarios should be mutually exclusive. That is, each investigation should be applicable to only one

scenario. The last limitation is that each scenario should have human factors as its chief consideration in its description.

## H. HAZARDOUS MATERIALS

### 1. Background

Sacarello (1993) defines hazardous materials as "a broad term encompassing any material, including substances and wastes, that may pose an unreasonable risk to health, safety, property, or the environment, when they exist in specific quantities and forms" (Introduction). Inspection, handling, cleanup, and personal safety issues regarding hazardous materials got their start from the chemical industry and the U.S. Army's Chemical Warfare Program. An insecticide known as Paris Green was used as early as 1865 and in 1910, Congress set standards for this product and other pesticides. In 1947, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) was adopted. FIFRA is a guideline for pesticide registration and labeling. This legislation gave way to further control over pesticides through the U. S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA). The early concern over pesticides stems from the fact that they are among the most toxic substances produced by the chemical industry.

Environmental and training regulations were greatly enhanced in 1970. First, the National Environmental Policy Act (NEPA) was signed. NEPA was drafted to reflect a concern about the environmental consequences of the dealings of federal agencies, and its chief objective is to encourage a productive harmony between man and his environment. This is partly achieved through the use of an Environmental Impact Statement (EIS). NEPA requires that a detailed EIS be prepared for every major federal action that significantly affects the quality of the human environment. The EIS addresses such issues

as the environmental impact of the proposed action, any adverse environmental effects that cannot be avoided, and possible alternatives.

In December of 1970, the Occupational Safety and Health Act (OSHA) was enacted and the EPA was created. OSHA is the result of various efforts, some successful and some not, regarding worker safety. The three main roles of OSHA are;

1. Setting the safety and health standards
2. Their enforcement through federal and state inspectors
3. Public education consultation (Sacarello, 1993 p. 9)

OSHA is generally applicable to facilities of ten or more employees. This includes federal employees or other federal agencies. As far as hazardous materials are concerned, OSHA addresses health standards, cancer policy, hazard communication standard, and hazardous waste operations and training.

With the creation of the EPA, all federal activities on air and water pollution, solid wastes, pesticides, noise and environmental radiation were consolidated. This agency watches over such things such as streams, air sheds, acid rain, ocean dumping, and medical waste. Other legislation in the area of environmental and training regulations have included the Clean Air Act (1963), the Clean Water Act (1972), the Safe Drinking Water Act (1974), the Toxic Substances Control Act (1976), and the Hazardous Materials Transportation Act (1975).

### 2. Chemical Properties

In any discussion of hazardous materials, one must define the chemical properties of the hazardous materials to understand what makes them hazardous. The ways in which a chemical or chemical mixture may be hazardous is as follows:

1. The material presents a fire danger. It is explosive, flammable, or undergoes a reaction that releases heat.

2. The material is a cryogen. It presents a hazard due to its extremely cold physical state.
3. The material is toxic. Depending on the concentration, duration, and type of exposure, the material may cause sickness or even death.
4. The material is radioactive. Exposure induces reactions in human tissues that can cause cell death. (Sacarello, 1993, p.69, 71)

These are only broad categories used to describe how a chemical may be hazardous. It may be necessary to refer to a Material Safety Data Sheet for any given chemical to get a fuller understanding of how hazardous it is.

Like the chemical properties of a hazardous material, its' physical state may dictate how dangerous it is. The different terms used to describe the various physical states of a material are as follows (Sacarello, 1993): dust (size ranges from .1 to 25 micron), fumes (solid particles generated by condensation from the gaseous state), smoke (carbon or soot particles less than .1 micron in size which result from the incomplete combustion of carbonaceous materials such as coal or oil), aerosols (liquid droplets or solid particles dispersed in air that are of fine enough particle size to remain so dispersed for a period of time), mists(suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, or atomizing), gases (formless fluids that occupy the space or enclosure and can be changed to the liquid or solid state only by the combined effect of increased or decreased temperature), and vapors (gaseous form of a substance which are normally in the solid or liquid state). These states can directly determine the danger posed by a material since a material that is dangerous in one state may be quite harmless in another.

### 3. Toxicology

Toxicology is the study of chemical or physical agents that produce adverse responses in the biologic systems with which they interact (Handley, 1977). There are many different types of toxicologists, but they all perform at least one of two basic functions: 1) examine the nature of the adverse effects produced by chemicals or physical agents, and 2) to assess the probability of their occurrence. An industrial toxicologist is one specific type of toxicologist that is concerned with disorders produced in individuals who have been exposed to harmful materials where they work.

While toxic substances can be measured, studied, etc. in a wide variety of ways there are a few specific categories into which they can be defined. The first category to be discussed is by the duration of their effects. Substances, which are considered to have an acute toxicity property, generally have a sudden onset for a short period of time. The response is a reversible effect and lasts no longer than 24 hours. The responses of substances, which are considered to be chronic, are marked by long or permanent duration and are constant or continuous. The affects are considered to be permanent or irreversible. Some of the variables, which need to be considered when evaluating these types of effects, are route of exposure, sex, and age. Each of these factors can influence the affect of the toxicity of a substance.

Another way toxic substances can be defined is by their general site of action. Local toxicity means it occurs at the site of application or exposure. Systemic toxicity requires absorption of the toxicant via the bloodstream to susceptible organ(s), which are the sites of action (Sacarello, 1993).

In order to prevent the harmful affects of toxic substances, it is important to first understand what they are, but also how they can harm you. There are only three ways that chemical agents can harm an individual. The first is by contact with or absorption through the respiratory tract. This usually involves inhalation of toxic agents. The second way is by contact with or absorption through the skin. This occurs upon exposure to a toxic agent. This is a case where respiratory protection may not be adequate. Some toxic substances may pass through the skin, thereby making the respiratory equipment useless. The third way is by contact with or absorption through the digestive tract. This would involve consumption of the material in question.

**4. Controls**

Most control strategies can be categorized into one of four different ways: engineering; ventilation; personal protective equipment; and administrative controls. Engineering controls include such methods as replacing hazardous materials with less toxic materials or designing processes or controls to limit the exposure to such materials. Ventilation involves the trapping or removal of contaminated air. Personal protective equipment is used to provide a barrier between the individual involved and the hazard. Administrative controls involve such strategies as adjusting schedules to limit exposure of employees to hazardous conditions

There are many ways to protect individuals from the affects of toxic substances. The following is a list of general methods that may be used to control environmental factors or stresses that may cause sickness, impaired health, or significant discomfort among workers (Sacarello, 1993). They include;

1. Substitution of a less harmful material for one which is dangerous to health.
2. Change or alteration of a process to minimize worker contact.

3. Isolation or enclosure of a process of work operation to reduce the number of persons exposed.
4. Wet methods to reduce generation of dust in operations such as mining, quarrying, and drilling.
5. Local exhaust at the point of generation or dispersion of contaminants.
6. General or dilution ventilation with clean air to provide a safe atmosphere.
7. Personal protective devices, such as special clothing or eye and respiratory protection.
8. Good housekeeping, including cleanliness of the workplace, waste disposal, adequate washing, toilet, and eating facilities, healthful drinking water, and control of insects and rodents.
9. Special control methods for specific hazards, such as reduction of exposure time, film badges and similar monitoring devices, continuous sampling with preset alarms, and medical programs to detect intake of toxic materials.
10. Medical controls.
11. Training and education to supplement engineering controls. (p. 179)

While the previous controls are aimed at reducing or eliminating potential hazards, the use of personal protective equipment (PPE) is designed to help for emergency or temporary use only and even PPE may not be sufficient.

A study by Schmidt, Petree, and McDaniel (1984) of 448 eye injury cases, indicated that in over 95% of these cases the majority of workers had complied with the local policies, but still suffered an eye injury. While local policies may dictate that eye protection be worn, there are various forms of eye protection available. Face shields, goggles, etc. all provide protection, but for different possible accidents.

The most important factor in determining the proper PPE is to first determine what chemicals the employee will be exposed to. Other factors to be considered include the concentration of the chemicals in the air, liquid, or solid state, the length of exposure, abrasion, dexterity, ability to decontaminate, climatic conditions, work load, and reflective clothing.

## I. SUMMARY

Accident databases, while helpful when taken in context, should not be used as the only tool in evaluating, analyzing, and reporting on accidents. Human factors can often go beyond normal statistics and require other methods of investigation. Also, the best place to start is in the design phase of any operation or equipment, not after accidents have started to occur.

When it comes to hazardous materials, this same theory holds true. The best way to avoid accidents is to first try to eliminate the hazard itself. When this is not possible the next best tactic is to try to reduce the amount of exposure through various controls. After the dangers from exposure to the hazard have been reduced as much as possible, the next form of defense is proper PPE. Even this step is not as self-evident as it would seem. First the type of hazard should be determined, and then exposures and possible dangers evaluated.

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# III. METHODOLOGY

## A. RESEARCH APPROACH

This study involves the analysis and evaluation of Special Case Mishap (SCM) reports as maintained by the Naval Safety Center (NSC). The SCM reports selected for analysis are those that: (1) pertain to all cases of hazardous material, chemical, or toxic exposure; (2) involve military personnel who require medical attention and are assigned aboard ships and submarines; and (3) occur in the calendar years of 1994 through 1998. Descriptive statistics and categorical data analysis are used to identify common traits among individuals. Human factors analysis is conducted to identify actions, inactions, or events that contribute to this type of mishap. A stochastic model of hazardous material mishap episodes is developed to predict event frequency. Results are compared with those of other categories of mishaps for further insight.

## B. HAZARDOUS MATERIAL EXPOSURES

SCM reports are required to be submitted in accordance with OPNAVINST 5100.19C (Department of the Navy, 1997) for all cases of electric shock, hazardous material (HAZMAT), chemical, or toxic exposure requiring medical attention, back injuries requiring medical attention, and all mishaps involving explosives, oxidizers, incendiaries, explosive systems, or chemical warfare agents. These reports are submitted via standard message format within 30 calendar days of event occurrence. SCM reports contain information related to the mishap such as date, time, location, personal and property cost, fatality/injuries summary, and a variety of statistics about the individual, accident and ship involved (see Appendix A). Once a SCM is reported, the NSC enters the data from the report into their Safety Information Management System (SIMS). A

query of all hazardous material mishaps for the calendar years of 1994 through 1998 yielded a total of 627 events involving 820 personnel.

## C. PROCEDURE

SIMS utilizes a relational database with an ability to query on any of the presented data fields. Extraction of data as requested from SIMS is returned in ASCII text format. This report format is converted to a Microsoft Excel 97 (1997) format by using Monarch (1995), a data access and analysis software program, for subsequent analysis. The spreadsheet generated by this conversion consists of rows that represent individuals involved in HAZMAT mishaps as previously outlined. Columns within the spreadsheet define individuals by vessel type, ship's status, ship's evolution, event serial number, date of occurrence, severity, rank/rate, rating, rank, sex, age, duty station, parent command, and primary body part affected. Narratives from the original ASCII text format are evaluated for human factors' concerns, evaluated and coded directly into the spreadsheet.

## D. DATA ANALYSIS

Descriptive statistics and categorical data analysis of HAZMAT mishap data are used to identify and evaluate common factors among individuals, commands and ships involved in these types of occurrences. In keeping with the theories presented by Goetsch (1996) and Drury & Brill (1983) who state that "etiological accident data from in-depth investigations can be used to derive meaningful hazard patterns", human factors analysis will examine several aspects of HAZMAT accidents. These aspects will include summary causal factors, detailed analysis of what caused the accident and why, the type of activity being performed by individuals at the time of the accident and specific analysis of PPE incidents.

This data is also used to fit the mishap events to a Poisson process. Both Sciretta (1999) and Lindly (1999) base their stochastic models on the observation that the mishap data in their studies is well modeled by Poisson distributions. Comparisons to other mishap categories are used to demonstrate common traits and reasons for differences among the data.

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# IV. RESULTS

## A. HAZARDOUS MATERIAL MISHAPS

For the period from CY94 – CY98 there are 627 hazardous material (HAZMAT) mishaps involving 820 personnel onboard U. S. Navy surface ships. There is a general increase in the number of mishaps and individuals involved from CY94 through CY96 and then a general decrease from that point forward. Table 1 gives the average number of HAZMAT mishaps per surface ship for CY94 through CY98 and the average number per 1,000 personnel assigned to surface ships for the same time frame.

| Mishap Rates | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Per Surface Ship | 0.42 | 0.49 | 0.58 | 0.44 | 0.39 |
| Per 1,000 Personnel | 0.95 | 1.09 | 1.26 | 0.96 | 0.99 |

**Table 1. HAZMAT Mishap Occurrence Rates by Year**

The average rate of mishap occurrences per ship for the time frame CY94 – CY98 is .46 and 1.05 for mishaps per 1,000 personnel. In both cases, CY96 is by far the worst year for the occurrence of HAZMAT mishaps with CY95 being the only other period with a higher than average mishap rate. CY98 mishap rates have managed to return to comparable CY94 rates. The number of personnel assigned to surface ships dropped by over 10,000 personnel from 1994 to 1995 and then remained relatively constant through 1997 before dropping another 17,816 from 1997 to 1998. The number of surface ships decreased from 297 on average in 1994 to 269 in 1995. This number remained relatively constant then throughout 1995 – 1998.

## B. DATA EXPLORATION

Of the 627 HAZMAT mishaps, 566, or 90.3% involve a single individual while the most number of individuals involved in an event for the same time period is 20. The average number of individuals involved in HAZMAT mishaps over this time frame is

1.31 with the highest rates occurring in CY96 and CY97. Table 2 summarizes the average number of personnel per mishap by parent command. AIRLANT, SURFPAC, and SURFLANT account for 80% of all personnel involved in HAZMAT mishaps for the years displayed. Overall, the number of multiple personnel involved in HAZMAT mishaps has declined from CY96 through CY98. Of the 153 HAZMAT mishaps in CY96, 12% involve more than one individual. Table 3 shows this number drops to 11% in CY97 and only 8% in CY98.

| Parent | 94 | 95 | 96 | 97 | 98 | Total |
|---|---|---|---|---|---|---|
| AIRLANT | 1.03 | 1.20 | 1.54 | 1.44 | 1.06 | 1.30 |
| SURFPAC | 1.43 | 1.10 | 1.18 | 1.60 | 1.06 | 1.27 |
| SURFLANT | 1.09 | 1.06 | 1.38 | 1.95 | 1.36 | 1.35 |
| OTHER | 2.00 | 1.12 | 1.11 | 1.18 | 1.36 | 1.33 |
| Total | 1.32 | 1.14 | 1.37 | 1.53 | 1.17 | 1.31 |

**Table 2. Mean Number of Personnel per HAZMAT Mishap by Year and Parent Command**

| Personnel | 1994 | 1995 | 1996 | 1997 | 1998 | Total |
|---|---|---|---|---|---|---|
| Single | 111 | 124 | 134 | 103 | 94 | 566 |
| Multiple | 13 | 8 | 19 | 13 | 8 | 61 |
| Total | 124 | 132 | 153 | 116 | 102 | 627 |
| Percent Multiple Personnel | 10% | 6% | 12% | 11% | 8% | 10% |

**Table 3. Number of Single and Multiple HAZMAT Mishap Events by Year**

Mishaps are classified according to severity depending on the dollar value and/or involvement of personnel fatalities/injuries. Table 4 summarizes HAZMAT mishaps by severity as classified for each individual involved in the mishap. Table 5 demonstrates the difference in severity levels by mishap for the four principle parent commands. While the overall percentages of mishaps are Class C at 17% and Class D at 81%, the percentages are quite different between air and surface parent commands. Both AIRPAC and AIRLANT severity classifications are split with about 10% as Class C mishaps and 89%

as Class D, while SURFPAC and SURFLANT are split about 23% Class C and 77% as Class D.

| Severity | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| A | 2 | 0 | 0 | 0 | 0 | 2 | 0.2 |
| B | 0 | 1 | 11 | 0 | 0 | 12 | 1.5 |
| C | 48 | 21 | 30 | 24 | 17 | 140 | 17.1 |
| D | 114 | 129 | 168 | 153 | 102 | 666 | 81.2 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 4. Individual HAZMAT Mishap Severity by Year**

| Parent | Severity | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|---|
| AIRLANT | A | 1 | 0 | 0 | 0 | 0 | 1 | 0.4 |
| | B | 0 | 0 | 2 | 0 | 0 | 2 | 0.8 |
| | C | 7 | 3 | 10 | 3 | 2 | 25 | 9.8 |
| | D | 30 | 58 | 56 | 51 | 33 | 228 | 89.1 |
| Total Mishaps | | 38 | 61 | 68 | 54 | 35 | 256 | |
| SURFPAC | A | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | B | 0 | 1 | 0 | 0 | 0 | 1 | 0.7 |
| | C | 10 | 7 | 3 | 3 | 9 | 32 | 23.7 |
| | D | 20 | 13 | 25 | 22 | 22 | 102 | 75.6 |
| Total Mishaps | | 30 | 21 | 28 | 25 | 31 | 135 | |
| SURFLANT | A | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | B | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | C | 11 | 4 | 4 | 3 | 2 | 24 | 21.8 |
| | D | 22 | 13 | 25 | 17 | 9 | 86 | 78.2 |
| Total Mishaps | | 33 | 17 | 29 | 20 | 11 | 110 | |
| AIRPAC | A | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | B | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| | C | 1 | 1 | 1 | 0 | 1 | 4 | 10.5 |
| | D | 1 | 10 | 12 | 6 | 5 | 34 | 89.5 |
| Total Mishaps | | 2 | 11 | 13 | 6 | 6 | 38 | |
| All Others | | 21 | 22 | 15 | 11 | 19 | 88 | |
| Grand Total | | 124 | 132 | 153 | 116 | 102 | 627 | |

**Table 5. HAZMAT Mishap Severity by Parent Command and Year**

Tables 6 and 7 and Figure 1 summarize the number of personnel involved in HAZMAT mishaps by gender, rank, and age respectively. The number of female personnel involved in HAZMAT mishaps has remained relatively constant from CY94 through CY98 while the number of male personnel involved has decreased significantly from CY96 to CY98. Of the 820 personnel involved in HAZMAT mishaps, 252, or 31%,

are E-3's. While safety reports indicate gender and rank for all 820 individuals involved in HAZMAT mishaps, there are only 765 reported ages. Of these 765 records, the median age is 23.6 and the mode is 20. The age and rank figures are in keeping with each other and with the type of work being performed.

| Gender | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Female | 17 | 19 | 16 | 14 | 17 | 83 | 10.1 |
| Male | 147 | 132 | 193 | 163 | 102 | 737 | 89.9 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 6. HAZMAT Mishaps by Gender and Year**

| Rank | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| E01 | 29 | 11 | 11 | 15 | 12 | 78 | 9.5 |
| E02 | 20 | 31 | 28 | 16 | 21 | 116 | 14.1 |
| E03 | 51 | 50 | 74 | 47 | 30 | 252 | 30.7 |
| E04 | 35 | 31 | 57 | 48 | 24 | 195 | 23.8 |
| E05 | 17 | 19 | 23 | 29 | 23 | 111 | 13.5 |
| E06 | 7 | 5 | 11 | 15 | 7 | 45 | 5.5 |
| E07 | 2 | 2 | 3 | 4 | 1 | 12 | 1.5 |
| Other | 3 | 2 | 2 | 3 | 1 | 11 | 1.3 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 7. HAZMAT Mishaps by Rank and Year**

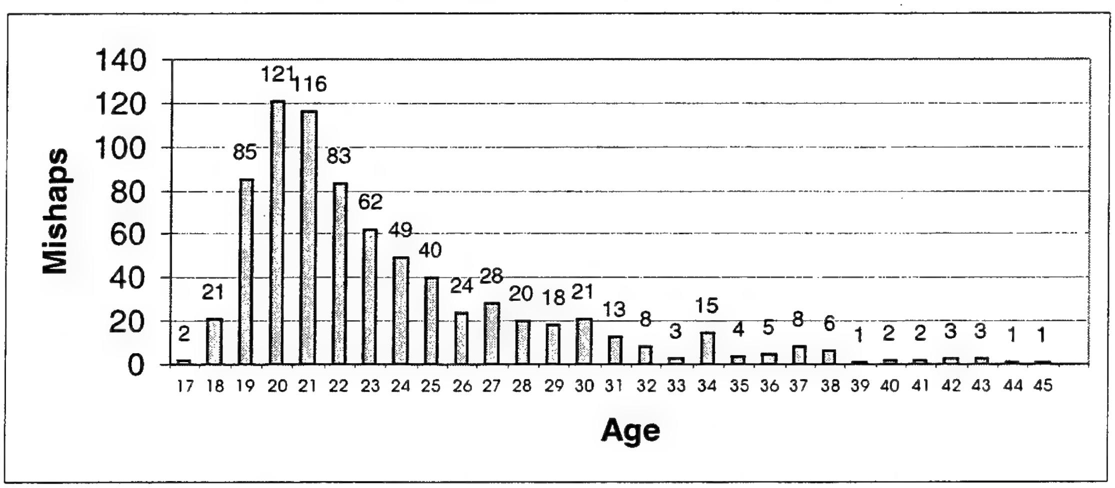


**Figure 1. Histogram of HAZMAT Mishap Victims by Age**

450 of the 820 personnel involved in HAZMAT mishaps suffer injuries to their eyes. This accounts for 55% of all injuries. The next highest total is for the lungs. Injuries to these body parts reduce slightly from CY96 to CY97, but saw drastic reductions from

CY97 to CY98. Injuries to eyes drop 35% and injuries to lungs drop 65%. All other categories of injuries to body parts remain relatively constant over the time frame studied. Table 8 summarizes this information.

| Body Part | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Eye | 81 | 95 | 106 | 102 | 66 | 450 | 54.9 |
| Lungs | 46 | 15 | 46 | 37 | 13 | 157 | 19.1 |
| Hand, Include Fingers | 5 | 7 | 18 | 7 | 4 | 41 | 5.0 |
| Face | 4 | 6 | 8 | 6 | 10 | 34 | 4.1 |
| Total Body | 2 | 8 | 3 | 9 | 11 | 33 | 4.0 |
| Arm, Lower | 8 | 3 | 2 | 5 | 0 | 18 | 2.2 |
| Multiple Body Parts | 4 | 2 | 8 | 0 | 2 | 16 | 2.0 |
| Other | 14 | 15 | 18 | 11 | 13 | 71 | 8.7 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 8. HAZMAT Mishaps by Body Part and Year**

Table 9 displays the vessel type that personnel involved in HAZMAT mishaps come from. As expected, the largest numbers of mishaps occur aboard Aircraft Carriers as they command the largest share of personnel versus any other ship type. Table 10 shows the percentage of personnel aboard Carriers versus all surface personnel against the percentage of mishaps occurring aboard Carriers against all surface ships. As this table shows, CY94 and CY98 show fairly even percentages while CY95 – CY97 show a disproportionate share of personnel involved in mishaps on board Carriers. This inequality is a major force in the higher rates seen in Table 1 for CY95 – CY97 for all HAZMAT mishaps.

| Vessel Type | 1994 | 1995 | 1996 | 1997 | 1998 | Total |
|---|---|---|---|---|---|---|
| Aircraft Carrier | 57 | 85 | 120 | 96 | 43 | 401 |
| Auxiliary | 69 | 30 | 19 | 14 | 27 | 159 |
| Landing Amphib | 13 | 13 | 29 | 16 | 25 | 96 |
| Cruiser | 3 | 3 | 3 | 31 | 4 | 44 |
| Destroyer | 8 | 6 | 15 | 7 | 3 | 39 |
| Patrol | 2 | 14 | 8 | 7 | 7 | 38 |
| Frigate | 11 | | 11 | 2 | 7 | 31 |
| Mine | 1 | | 4 | 4 | 3 | 12 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 |

**Table 9. HAZMAT Mishaps by Vessel Type and Year**

| Carrier Mishaps | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Carrier Personnel to All Surface Personnel | 29.8% | 30.9% | 30.9% | 30.7% | 34.0% |
| Carrier Mishaps to All Mishaps | 34.8% | 56.3% | 57.4% | 54.2% | 36.1% |

**Table 10. HAZMAT Mishap Rates for Carriers by Year**

Tables 11, 12, and 13 summarize information for personnel involved in HAZMAT mishaps in regards to the ship's evolution and status at the time of the mishap and the top ten duty stations of the personnel. The tables for ship's evolution and status show that the occurrence of HAZMAT mishaps to an individual are split fairly evenly between time spent underway, independent steaming and time spent moored while some type of maintenance or overhaul is performed. Table 13 shows the top ten duty stations as ranked by number of personnel involved in HAZMAT mishaps. Of the ten, eight are Aircraft Carriers, and these ten commands account for almost half of the personnel involved in all HAZMAT mishaps. The other two ships, the Normandy, a guided missile cruiser, has one mishap involving twenty people and the Camden, a fast combat support ship, has one mishap involving five people.

| Evolution | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Independent Steaming | 48 | 49 | 88 | 108 | 54 | 347 | 42.3 |
| Upkeep/Availability | 91 | 59 | 67 | 43 | 52 | 312 | 38.0 |
| Other | 13 | 27 | 17 | 20 | 9 | 86 | 10.5 |
| Overhaul | 12 | 16 | 37 | 6 | 4 | 75 | 9.1 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 11. HAZMAT Mishaps by Evolution and Year**

| Ship Status | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Underway | 57 | 62 | 102 | 125 | 63 | 409 | 49.9 |
| Moored (not in shipyard) | 81 | 65 | 62 | 45 | 50 | 303 | 37.0 |
| Shipyard Moored | 17 | 21 | 35 | 7 | 2 | 82 | 10.0 |
| Shipyard Drydocked | 3 | 2 | 7 | 0 | 3 | 15 | 1.8 |
| Anchored | 6 | 1 | 3 | 0 | 1 | 11 | 1.3 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 12. HAZMAT Mishaps by Ship Status and Year**

| Duty Station | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Dwight D Eisenhower | 8 | 6 | 22 | 26 | 18 | 80 | 9.8 |
| George Washington | 1 | 26 | 17 | 15 | 2 | 61 | 7.4 |
| John C Stennis | 1 | 14 | 19 | 9 | 6 | 49 | 6.0 |
| Theodore Roosevelt | 9 | 14 | 23 | 1 | 0 | 47 | 5.7 |
| John F Kennedy | 0 | 2 | 20 | 19 | 4 | 45 | 5.5 |
| Enterprise | 9 | 7 | 4 | 7 | 7 | 34 | 4.1 |
| Abraham Lincoln | 15 | 3 | 3 | 5 | 0 | 26 | 3.2 |
| Normandy | 0 | 0 | 0 | 20 | 0 | 20 | 2.4 |
| Nimitz | 0 | 3 | 9 | 2 | 3 | 17 | 2.1 |
| Camden | 7 | 1 | 1 | 1 | 6 | 16 | 2.0 |
| Total | 50 | 76 | 118 | 105 | 46 | 395 | 48.2 |

**Table 13. HAZMAT Mishaps by Duty Station and Year**

Table 14 displays HAZMAT mishap data by parent command. SURFPAC and SURFLANT both report approximately the same number of mishaps while AIRLANT and AIRPAC both report quite different results. This could be indicative of a varying degree of mission requirements, training, or reporting techniques between the air groups. To determine if any differences do exist, the number of mishaps for these four groups is first normalized by dividing the number of mishaps by the respective number of personnel within each group. The normalized rates are given in Table 15.

From Table 15 AIRPACS rates are constantly lower than AIRLANT for all five years. If mishaps actually occur at equal rates for the Atlantic and Pacific groups, there is a 50% chance in any given year that one group will have a higher rate than the other. In addition, the chance that one group's rates are higher than the other five years in a row is two to the fifth power, or one in thirty-two chances. This suggests that there is a

difference between AIRPAC and AIRLANT and further suggests the existence of other factors as stated previously causing a difference in the air groups data.

| Parent | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| AIRLANT | 39 | 73 | 105 | 78 | 37 | 332 | 40.5 |
| SURFPAC | 43 | 23 | 33 | 40 | 33 | 172 | 21.0 |
| SURFLANT | 36 | 18 | 40 | 39 | 15 | 148 | 18.0 |
| AIRPAC | 15 | 11 | 14 | 8 | 6 | 54 | 6.6 |
| SUBLANT | 11 | 8 | 6 | 2 | 3 | 30 | 3.7 |
| SUBPAC | 17 | 4 | 3 | 3 | 3 | 30 | 3.7 |
| Other | 3 | 14 | 8 | 7 | 22 | 54 | 6.6 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 14. HAZMAT Mishaps by Parent Command and Year**

| *Air Groups* | | | | | |
|---|---|---|---|---|---|
| ***Normalized Data*** | **1994** | **1995** | **1996** | **1997** | **1998** |
| AIRLANT | 0.00181 | 0.00314 | 0.00347 | 0.00277 | 0.00180 |
| AIRPAC | 0.00014 | 0.00086 | 0.00102 | 0.00049 | 0.00056 |
| ***Surface Groups*** | | | | | |
| ***Normalized Data*** | **1994** | **1995** | **1996** | **1997** | **1998** |
| SURFPAC | 0.00066 | 0.00048 | 0.00063 | 0.00061 | 0.00090 |
| SURFLANT | 0.00074 | 0.00042 | 0.00073 | 0.00050 | 0.00033 |

**Table 15. Normalized HAZMAT Mishap Data by Surface and Air Groups by Year**

## C. HUMAN FACTORS ANALYSIS

In their discussion of the human factors theory, Heinrich, Peterson & Roos (1980) focus on a chain of events leading to an accident with the root cause being attributable to some form of human error. An analysis of causal factors of the hazardous material mishaps indicates that 89.2% are attributable to human factors. The environment causes another 6.6% and the remaining 4.2% are caused by other factors.

There are four primary activities that individuals are involved in at the time of the HAZMAT mishap. These four activities are maintenance (27.7%), housekeeping (18.9%), material handling (14.6%), and damage control/emergency response (10.6%). As presented in the literature, any discussion of hazardous materials begins with defining the chemical properties of the hazardous materials. These activities all share a common

thread in that some type of chemical interaction, either working with a material that presents a fire danger or one that is toxic, is inevitable. Table 16 summarizes the main activities described in the data.

| Action | 1994 | 1995 | 1996 | 1997 | 1998 | Total | Percent |
|---|---|---|---|---|---|---|---|
| Maintenance | 55 | 38 | 52 | 42 | 40 | 227 | 27.7 |
| Housekeeping | 26 | 39 | 43 | 27 | 20 | 155 | 18.9 |
| Handling | 21 | 23 | 41 | 20 | 15 | 120 | 14.6 |
| Damage Control / Emerg Response | 23 | 8 | 21 | 22 | 13 | 87 | 10.6 |
| Installation / Removal | 5 | 17 | 12 | 9 | 4 | 47 | 5.7 |
| Watch | 11 | 2 | 14 | 8 | 2 | 37 | 4.5 |
| Aviation | 2 | 9 | 2 | 7 | 12 | 32 | 3.9 |
| Rigging Activities | | | | 21 | 1 | 22 | 2.7 |
| Walking/Stepping | 5 | 2 | 8 | | 4 | 19 | 2.3 |
| Inspecting | | 5 | | 4 | 3 | 12 | 1.5 |
| Other | 16 | 8 | 16 | 17 | 5 | 62 | 7.6 |
| Total | 164 | 151 | 209 | 177 | 119 | 820 | 100.0 |

**Table 16. HAZMAT Mishap Activities by Year**

As suggested by the literature, the best ways to avoid HAZMAT accidents are to eliminate the hazard or reduce the amount of exposure through various controls. After this, the next line of defense is proper personal protective equipment (PPE). An analysis of the HAZMAT data indicates that the primary reason given for what caused the accident is the failure to use PPE. This cause is named 336 times in the reports (30.0%), which in some cases give more than one cause for a given accident. In all, 1,119 causes are cited for the 820 HAZMAT mishaps. The next two most frequent causes relate to either a failure to recognize a hazardous situation, or failure to use proper caution when the individual knew the risk involved with the situation. Combined, these three factors account for about two-thirds of all causes named in the reports. Another 35 factors are cited that account for the remaining one-third of the factors (see Table 17).

| What | Total | Percent |
|---|---|---|
| Failed To Use Protective Equipment | 336 | 30.0 |
| Failed To Recognize Hazardous Situation | 275 | 24.6 |
| Failed To Use Proper Caution For Known Risk | 121 | 10.8 |
| Failed To Use/Properly Use Tool/Equipment For Job | 43 | 3.8 |
| Failed To Provide A Safe Work Environment | 38 | 3.4 |
| Failed To Follow Other Standard Operating Procedures | 37 | 3.3 |
| Failed To Plan Adequately | 34 | 3.0 |
| Failed To Take Corrective Action (Time Was Available) | 32 | 2.9 |
| Failed To Perform Pms/Maint Properly/Completely | 29 | 2.6 |
| Exploded | 20 | 1.8 |
| Failed To Coordinate Tasks | 18 | 1.6 |
| Inadequate | 16 | 1.4 |
| Leaking | 13 | 1.2 |
| Defective | 12 | 1.1 |
| Cracked | 11 | 1.0 |
| Failed To Supervise Progress Of Work | 11 | 1.0 |
| Other | 73 | 6.5 |
| Total | 1119 | 100.0 |

**Table 17. HAZMAT Mishap Causes**

In addition to identifying what cause is the basis of the accident, the SCMs also attempt to identify a reason associated with the cause. This data is summarized in Table18. Over 45 percent of the causes are directly attributed to the individuals' own negligence in the form of inattentiveness, haste, or lack of concern or interest. Another 25 percent are attributed to the individuals' deficiency of experience or knowledge as being a factor in the mishap.

| WHY | Total | Percent |
|---|---|---|
| Inattentive | 324 | 29.0 |
| Insufficient Experience/Skill/Training | 125 | 11.2 |
| Haste | 101 | 9.0 |
| Lack Of Concern/Interest | 79 | 7.1 |
| Inadequate Knowledge Of Men/Equipment | 76 | 6.8 |
| Task Fixation | 72 | 6.4 |
| Overconfidence | 63 | 5.6 |
| Not Convenient/Comfortable | 40 | 3.6 |
| Habit | 36 | 3.2 |
| Design Problem | 25 | 2.2 |
| Lack Of Ability Apart From Training/Experience | 25 | 2.2 |
| Inadequate/Unavailable Tools/Equipment | 17 | 1.5 |
| Normal Wear | 14 | 1.3 |
| Critical Steps Omitted | 13 | 1.2 |
| Distracted | 12 | 1.1 |
| Other | 97 | 8.7 |
| Total | 1119 | 100.0 |

**Table 18. HAZMAT Mishaps – Why**

More specific information for 236 individuals in regards to the use or non-use of PPE and their part in the mishaps is available from the SCMs. Of these 236 individuals, 172 report that PPE is a requirement and available for the situation, but not used. The SCMs report not using the PPE results in increased injury. 49 individuals are reported as having PPE available and used. Of these 49 cases, 36 cases result in reduced injury and 13 as using the wrong PPE. 13 cases are reported has not having PPE available, but require it resulting in increased injury to the individual.

## D. POISSON MODEL OF MISHAPS

Previous studies of mishaps, Sciretta (1999) and Lindly (1999), have successfully modeled mishaps occurring over time as homogeneous Poisson processes. The purpose of such modeling is to estimate the expected number of days lost and expected cost due to mishaps. A consequence of such a model is that the total number of mishaps has a Poisson distribution. Because we focus on five years of data rather than trying to model

mishaps over time as a Poisson Process, we model the total number of mishaps as a Poisson random variable.

Let the random variable X represent the total number of mishaps over a five-year period. If the distribution of X is Poisson with an expected value $\lambda > 0$, the probability mass function is of the form:

$$\Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} \quad k = 0, 1, 2 \ldots .$$

The parameter $\lambda$ (the expected number of mishaps in five years) must be estimated from the data. The maximum likelihood estimator (MLE) of $\lambda$, based on a simple random sample, is the sample mean $\overline{X}$. Here $\lambda$ is estimated to be 10.383 over the five years and the estimated expected number of observations with k mishaps, k=0,1,2... are given in Appendix B. A $\chi^2$ - goodness of fit test is performed to test the null hypothesis that the data is generated by a Poisson distribution. The data are partitioned in to thirteen classes and the chi-squared test statistic $\chi^2$ is computed as:

$$\chi^2 = \sum_{i=1}^{13} \frac{(O_i - E_i)^2}{E_i},$$

where $O_i$ and $E_i$ are respectively the observed and estimated expected frequencies in class i. These values are also given in Appendix B. The resulting test statistic is 9.849 with a p-value of .544. Thus, the null hypothesis that the distribution of HAZMAT mishaps is Poisson cannot be rejected at any reasonable level of significance. This in turn means that future events may be modeled and compared to already established rates to determine trends and possible adjustments to preventive strategies.

## E. MISHAP COMPARISONS

Through the comparison of the three primary types of mishaps reported via SCM reports, various commonalities and differences may be detected. Figure 2 presents the mishap occurrence rates per surface ship for HAZMAT, electrical shock, and back injuries. Figure 3 displays the rates per thousand personnel for the same mishaps. Electrical shock data is not readily available for 1998. As these figures show, electrical shock mishaps are much more prevalent over this time frame while HAZMAT mishaps occurred at the lowest rate. Attempts to apply simple linear regression analysis to the data points proved futile due to the small number of data points.

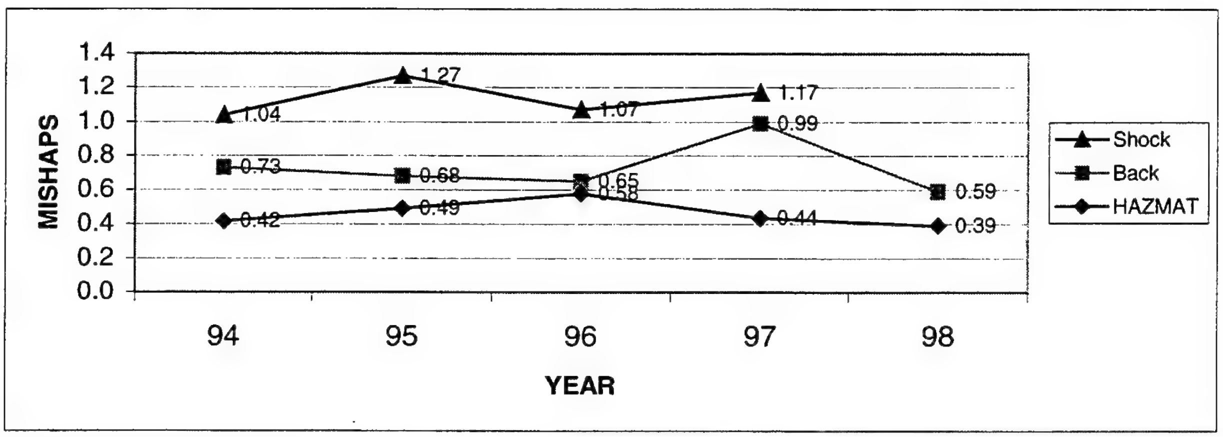


**Figure 2. Mishap Occurrences Per Ship**

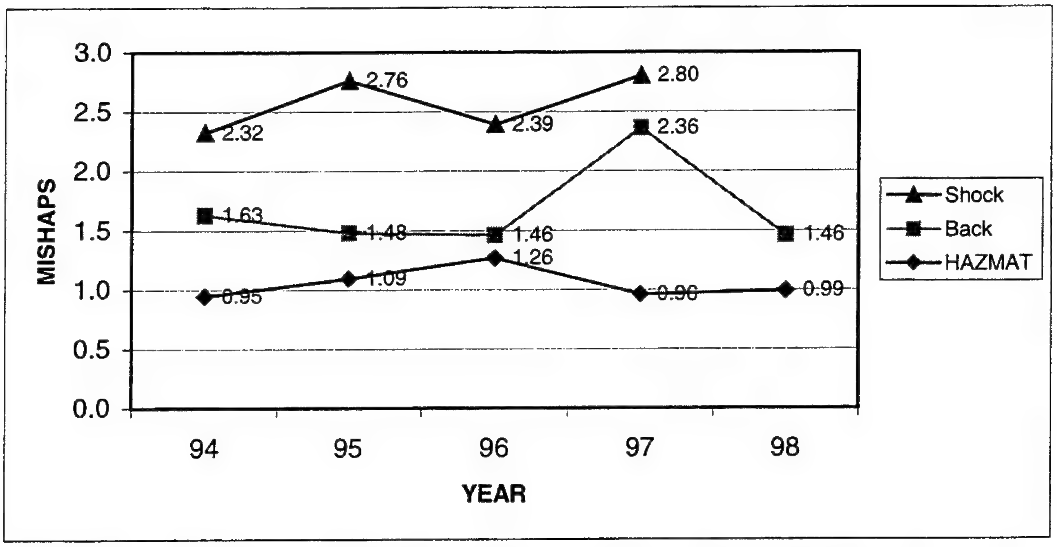


**Figure 3. Mishap Occurrences per 1,000 Personnel**

Figures 4, 5, 6, and 7 show the percentages of mishaps by severity, ship type, rank, and gender. In regards to these figures, data for HAZMAT and back injuries cover 1994 through 1998 while electrical shock data is for the period from 1995 through 1997. The percentage of Class A and Class B mishaps for all three types of mishaps are relatively negligible as shown in Figure 4, but there are some differences in the other two categories. Back injuries have a much higher percentage of Class C mishaps compared to HAZMAT or electrical shock mishaps, suggesting that these injuries tend to be more serious in nature than the other types. Roughly 93% of electrical shock mishaps are Class D. This suggests they are the least serious from an injury standpoint.

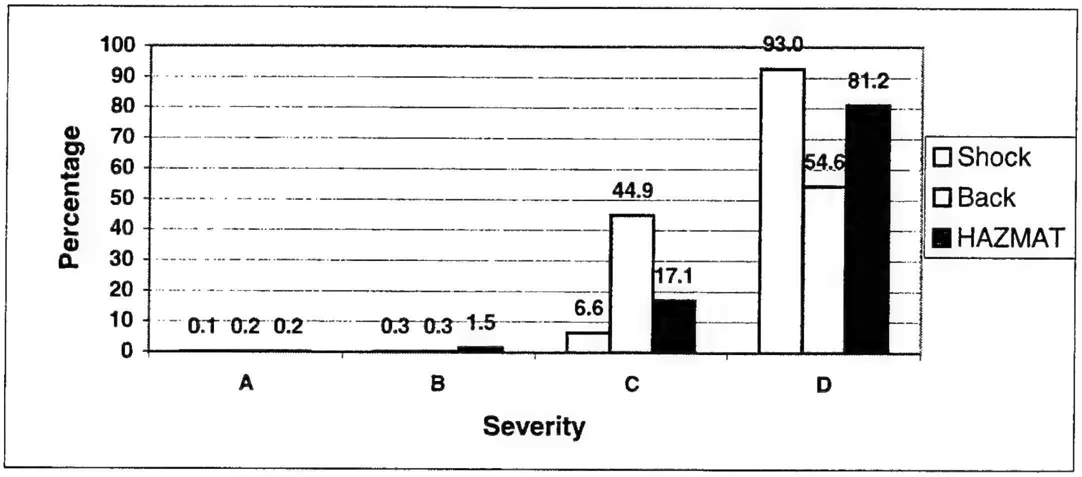


**Figure 4. Mishap Occurrences by Severity**

Figure 5 displays the percentage of each type of mishap by ship type. Carriers account for a vast majority of the HAZMAT mishaps (49%), while the mishaps for back injuries and electrical shock are somewhat more evenly distributed. Electrical shock mishaps tend to occur more often on Carriers and combatants while back injuries occur more often on Carriers and auxiliaries.

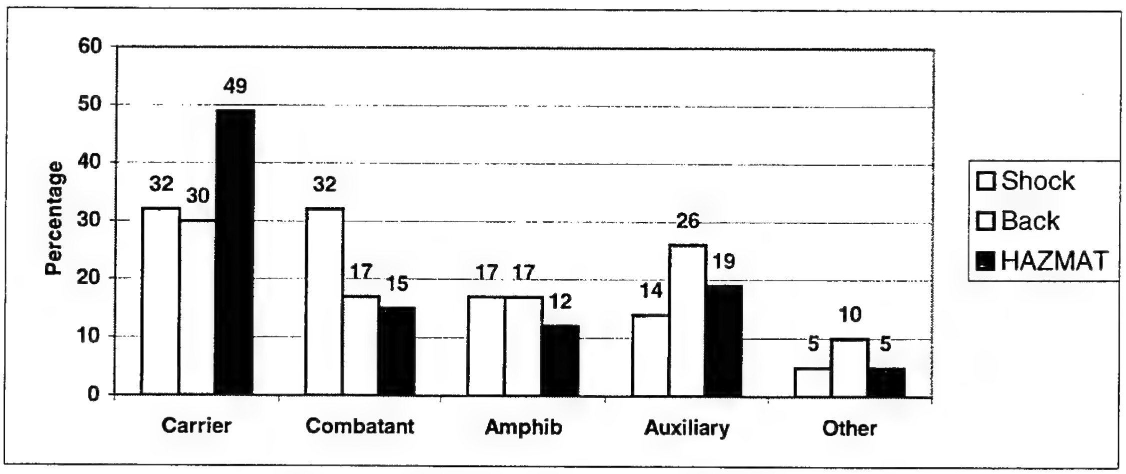


**Figure 5. Mishap Occurrences by Ship Type**

Figure 6 shows percentages of mishaps by rank. Electrical shock and back injuries are normally distributed about the E-04 rank. HAZMAT mishaps tend to be positively

skewed towards the lower ranks. Of the three mishap types, at least two-thirds of all mishaps occur in the E-03 to E-05 rank range.

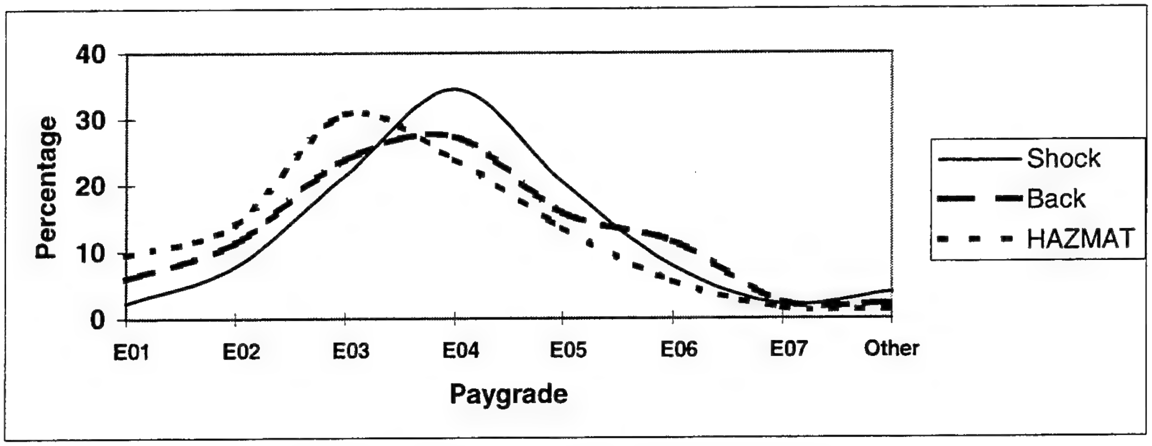


**Figure 6. Mishap Occurrences by Rank**

Figure 7 displays the percentages of mishaps by gender. At a 5% level of significance the proportion of electrical shock mishaps attributable to males is greater than for back or HAZMAT mishaps attributable to males (94.3% versus 89.9% 87.2% respectively). There does not appear to be differences in the proportion of back and HAZMAT mishaps attributable to males.

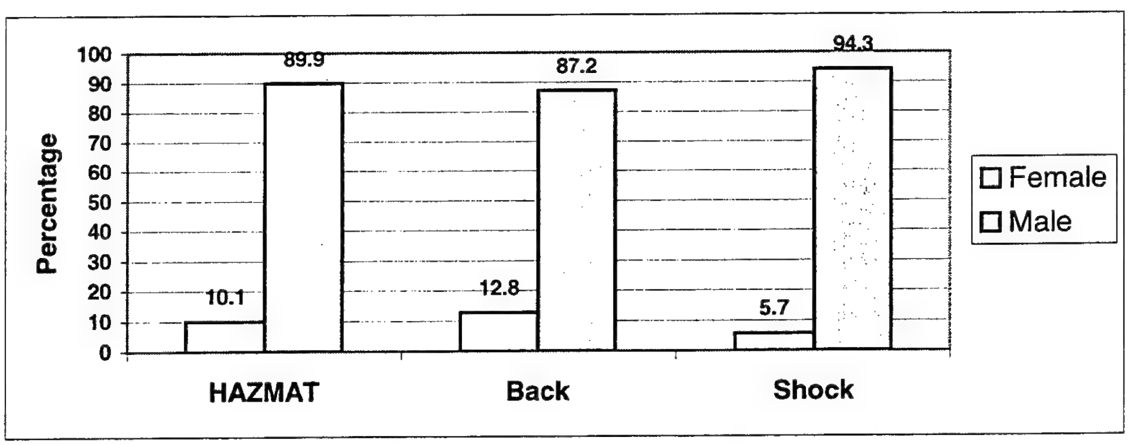


**Figure 7. Mishap Occurrences by Gender**

Of the four categories of variables compared for mishaps, electrical shock mishaps are clearly more defined. Electrical shock mishaps account for the highest

percentage of Class D mishaps at 93.0%, highest percentage for an individual rank, E-04 at 34.5%, and gender, males at 94.3%. The only exception being ship type where HAZMAT mishaps on Carriers account for 48.9% of all HAZMAT mishaps.

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# V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. SUMMARY

Chemicals and other hazardous materials (HAZMAT) are unavoidable aboard U.S. Navy vessels. Interaction with these materials requires personnel to adhere to established safety measures to avoid injury. For the period from January 1, 1994 through December 31, 1998, there are 627 HAZMAT mishaps involving 820 personnel onboard U. S. Navy surface ships. There are many opportunities to improve safety and readiness while reducing the number of workdays lost to injury, due to the nature of this type of risk.

Reactions to toxic materials may vary greatly depending on whether the material is explosive or flammable, a cryogen, toxic, or radioactive. There are three ways that chemical agents can harm an individual. The first is by contact with or absorption through the respiratory tract. The second way is by contact with or absorption through the skin. The third way is by contact with or absorption through the digestive tract. This would involve consumption of the material in question.

For the time frame from CY94 – CY98 the number of HAZMAT mishaps per surface ship ranges from .39 to .58 and the same number of mishaps per thousand personnel ranges from .95 to 1.26. Of the 627 mishaps for this time frame a vast majority involve a single individual (90.3%), are of Class "C" or less in severity (98.3%), and involve males (89.9%). The reported median age for an individual involved in a HAZMAT mishap is 23.6 years of age and the most common rank is E-3 (30.7%). Most injuries incurred by individuals are either to their eyes (54.9%) or to their lungs (19.1%). Almost half (48.9%) of personnel involved in HAZMAT mishaps are attached to Carriers

and 42.3% are injured while the ship's evolution is classified as independent steaming. SURFPAC and SURFLANT report similar levels of mishaps while AIRLANT reports a much greater level of mishaps than SURFLANT. This may be indicative of varying training, reporting techniques, or mission requirements.

A human factors analysis of the data reveals that over 89% of the mishaps in this study are attributable to human error. Another 6.6% are attributable to the environment. Individuals involved in either maintenance (27.7%) or housekeeping (18.9%) actions account for a majority of the mishaps. Among the reasons given for what caused the HAZMAT mishap are failure to use personal protective equipment (PPE, 30.0%), failure to recognize a hazardous situation (24.6%), and failure to use proper caution for a known risk (10.8%). The main reason given for why this happens is due to the individual's inattentiveness (29.0%) followed by insufficient experience, skill, or training (11.2%) and haste (9.0%).

Finally, HAZMAT mishaps are compared with the other two main types of reported mishaps, electrical shock and back injuries. Overall, electrical shock mishaps occurred with greater frequency than either back injuries or HAZMAT mishaps, but with less severity. 93.0% of electrical shock mishaps are Class "D" compared with 54.6% for back injuries and 81.2% for HAZMAT. HAZMAT mishaps are more frequent between E-3's while back injury and electrical shock mishaps center more around the E-4 rank. As a percentage of all individuals involved in mishaps, occurrences of mishaps to males are higher among electrical shock mishap victims (94.3%) as compared to HAZMAT (89.9%) or back injury (87.2%) victims.

## B. CONCLUSIONS

As with electrical shock and back injury mishaps, HAZMAT injuries predominantly occur aboard Aircraft Carriers, but to a much greater degree. 49% of all mishaps in this study occur on Carriers as compared to 32% for electrical shock mishaps and 30% for back injuries. HAZMAT mishaps also tend to occur less frequently than the other two types of mishaps and in a slightly lower range of rank. Personnel suffer injuries to their eyes almost 55% of the time, which is fairly constant over the time frame studied.

Human factors analysis of HAZMAT mishaps indicates that 89.2% of those studied are attributable to human error. As with electrical shock mishaps, failure to use PPE or failure to use proper PPE is a central issue. 30.0% of the reasons given for what caused the HAZMAT mishap are attributed to a failure to use PPE. Reasons why the mishap occurred are also similar between HAZMAT and electrical shock mishaps. Inattentiveness, haste, and lack of concern or interest are three of the top four reasons given for the HAZMAT study.

The number of mishaps in a five-year period appears to have a Poisson distribution. This, along with similar results of Sciretta (1999) for electrical shocks and Lindly (1999) for back injuries, indicates that a Poisson process can adequately model these types of mishaps. Thus, future events may be modeled and compared to already established rates to determine trends and possible adjustments to preventive strategies.

Overall, several similarities and differences are noted between HAZMAT, electrical shock and back injury mishaps. Over the respective periods of study, most HAZMAT, electrical shock and back injury mishaps are relatively minor and occur aboard Carriers to personnel in the E-3 to E-5 range. While minor discrepancies exist

within the distribution of these data points, overall there are many commonalities that may be observed.

## C. RECOMMENDATIONS

Based on previous studies and recommendations it is obvious that a concerted effort focusing future intervention strategies at Aircraft Carriers is imperative. A combined training effort targeted at combating common root causes of all types of mishaps, if possible, could reduce all types of mishaps and save training time and money by addressing all issues at once. Based on all mishap studies, training should be targeted at the E-3 to E-5 range aboard Carriers, for all maintenance and housekeeping activities, stressing adherence to existing safety regulations.

Specifically, attention to causal factors including improper use of PPE, inattentiveness, and haste should be included. Procedures, particularly those that involve the proper use and purpose of PPE, should be reviewed and more strictly enforced. Training which emphasizes increased communication and application of proper procedures will not only reduce further mishaps, but also foster a culture of safety adherence.

Human factors analysis indicates that human error is a primary cause of all types of mishaps, yet reporting and presentation of such data in this area is extremely limited. Changes to OPNAVINST 5100.19C would seem prudent given the current situation. Enhanced reporting of human factors elements would improve analysis and enable more detailed study of existing conditions and recommendation of proper intervention strategies. This in turn would reduce costs and lost workdays due to these mishaps. Also, training of personnel reporting mishap data as well as of personnel inputting this

information at the Naval Safety Center (NSC) would insure consistency across the board and improve reporting.

Recent NSC initiatives such as Ship's Safety Bulletins and magazines indicate a degree of success in reducing mishaps in 1998 from 1997 rates. Continued awareness programs concentrating on previously discussed issues may help focus further efforts. Supplementary studies of 1999 data may help to determine the successfulness of such programs and provide insight to existing as well as new trends in mishap causation.

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# APPENDIX A. SPECIAL CASE MISHAP REPORT EXAMPLE

Event Serial: XXXXXX Date: XX/XX/XXXX Severity: D OPERATIONAL
DOD Mishap Catg: MARINE - UNDERWAY MISHAP Time:

Event Location (Ship, Sub, Small Craft): NO DATA

Cost Matrix:

| | | |
|---|---|---|
| Event Injury Cost: | $ | 0 |
| Event DOD Property Cost: | $ | 0 |
| Event NON-DOD Property Cost: | $ | 0 |
| Total Event Cost: | $ | 0 |

Fatalities/Injuries Occurring in Event:

| | Navy Mil | Navy Fed Civ | Other |
|---|---|---|---|
| Fatality (A,U,L) | 0 | 0 | 0 |
| Perm Total Dis (B) | 0 | 0 | 0 |
| Perm Partial Dis (C) | 0 | 0 | 0 |
| Major Injury (D) | 0 | 0 | 0 |
| Minor Injury (E) | 0 | 0 | 0 |
| First Aid (F) | 0 | 0 | 0 |
| No Injury (G) | 1 | 0 | 0 |
| Missing/Unknown (X) | 0 | 0 | 0 |

Source Documents:
Source Type: OPNAV FORM 5102-1 - PERSONNEL INJURY/DEATH REPORT
Reference ID: Date of Source:

Accountable Activity Data:
Involved Activity: UIC:
Environment: SHIP

INVOLVED ACTIVITY DATA:

Accountable Activity Indicator: YES

Involved Activity:
UIC:
Parent/Tycom:
Involved Acty: Vessel Type: Prototype Hull:

Reporting Activity: PLATTE
UIC: XXXXXX XX XXX Prototype Hull: XXX
Parent/Tycom: XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Reporting Acty: Vessel Type: XX Prototype Hull: XXX

Environment: SHIP

Ship Status: UNDERWAY
Evolution: INDEPENDENT STEAMING

Mishap Type: 1 CHEMICAL/TOXIC EXPOSURE
Mishap Type: 1 CHEMICAL/TOXIC EXPOSURE

Cost Matrix:
Number of Lost Operating Days for the Activity: 0

| | | |
|---|---|---|
| Activity Injury Cost | $ | 0 |
| Activity DOD Property Damage | $ | 0 |
| Activity NON-DOD Property Damage | $ | 0 |
| Total Activity Cost | $ | 0 |

Fatalities/Injuries Occurring at the Involved Activity:

| | Navy Mil | Navy Fed Civ | Other |
|---|---|---|---|
| Fatality (A,U,L) | 0 | 0 | 0 |
| Perm Total Dis (B) | 0 | 0 | 0 |
| Perm Partial Dis (C) | 0 | 0 | 0 |
| Major Injury (D) | 0 | 0 | 0 |
| Minor Injury (E) | 0 | 0 | 0 |
| First Aid (F) | 0 | 0 | 0 |
| No Injury (G) | 1 | 0 | 0 |
| Missing/Unknown (X) | 0 | 0 | 0 |

INJURED PERSON DATA:

Pers Catg: ENLISTED NON-AIRCREW
Service Status: NAVY
ACTIVE
Rank/Rate: FR Rating: FR Paygrade: E01

Sex: X Age: XX Duty Status: ON DUTY
Perm Duty Station: XXXXXX
UIC: XXXXXX XX XXX Prototype Hull: XXX
Parent/Tycom: XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

Overall Injury: NO INJURY, LIGHT DUTY, MINIMAL INJURY WITH NO LOST WORK TIME

Specific Injuries: (* denotes primary injury)
* Body Part: FACE
* Locn: TOTAL PART OR MULTIPLE BODY PARTS
* Diagnosis: BURN, CHEMICAL

Osha Occupational Ill?

Cost Matrix:

| | | |
|---|---|---|
| Injury Cost | $ | 0 |
| Number of Days Hospitalized | | 0 |
| Number of Days Restricted Activity | | 0 |
| Number of Lost Workdays | | 0 |

General Area: DECK SPACES
Specific Area: N.E.C. Compt No:
Job Catg:
Job/Action: HOUSEKEEPING
Experience with this Job/Action: Months Hrs Awake Prior to Event:
Object Involved: CHEMICALS/TOXICS
Accident Type: CONTACT W/ RADIATION/CAUSTIC/TOXIC/NOXIOUS SUBSTANCES

Injury Mishap Type: CHEMICAL/TOXIC EXPOSURE

Training Type: NO DATA

Chemical/Toxic Exposure Data:
General Catg: SKIN IRRITANTS
Specific Catg: OTHER
How Exposed: CONTACT Hours Minutes
Level of Exposure:

Drug Factors: NO DATA

Personnel Protective Equipment:
Equip: GLASSES/GOGGLES; SHIELD, EYE/FACE, CLEAR
Need/Avail? AVAILABLE, NOT USED
Factor in Injury? INCREASED INJURY/NON-USE INCREASED INJURY
Effectiveness?
If Not, Why?

General Cause Factors: UNDETERMINED DUE TO INSUFFICIENT FACTS

Specific Personnel Cause Factors: NO DATA

Specific Material Cause Factors: NO DATA

Specific Environmental Cause Factors: NO DATA

Specific Procedural Cause Factors: NO DATA

DAMAGED EQUIPMENT DATA: NO DATA

NARRATIVES:

Brief Narrative: no brief narrative available

Lessons Learned Narrative: no lessons learned narrative available

Event Narrative:
AT APPROX XXXX ON XX XXX XX, SNW WAS CLEANING SHIP'S BELL WITH KOH SOLUTION (OVEN CLEANER) WHEN A GUST OF WIND BLEW SOME OF SOLUTION ON TO HER FACE AND CLOTHES CAUSING FIRST DEGREE BURNS TO HER FACE AND LIPS. SNW WAS NOT WEARING ANY PROTECTIVE APPAREL. PERS WERE REMINDED THAT SHIP'S BELL AND OTHER BRASS ARTICLES ARE TO BE CLEANED ONLY WITH BRASS CLEANER AND THAT WHEN CHEMICAL CLEANER IS REQUIRED FOR ANY REASON (IE. PMS) THEY ARE TO BE PROPERLY DRESSED OUT (IE. GOGGLES, FACE SHIELD AND RUBBER GLOVES).

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# APPENDIX B. CY94 – CY98 STOCHASTIC MODELING OF HAZMAT MISHAPS

| Number of Mishaps | Observed Frequency $O_i$ | Estimated Expected Frequency $E_i$ | $\frac{(O_i - E_i)^2}{E_i}$ |
|---|---|---|---|
| <=5 | 4 | 3.234 | .181 |
| 6 | 3 | 3.232 | .017 |
| 7 | 4 | 4.794 | .131 |
| 8 | 5 | 6.222 | .240 |
| 9 | 11 | 7.178 | 2.035 |
| 10 | 9 | 7.453 | .321 |
| 11 | 6 | 7.035 | .152 |
| 12 | 5 | 6.087 | .194 |
| 13 | 1 | 4.862 | 3.068 |
| 14 | 2 | 3.606 | .715 |
| 15 | 3 | 2.496 | .102 |
| 16 | 3 | 1.620 | 1.176 |
| >=17 | 4 | 2.181 | 1.516 |
| | 60 | 60 | 9.849 |

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